A Slower Superluminal Velocity for the Quasar 1156+295

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ABSTRACT

As part of an ongoing effort to observe high energy γ-ray blazars with VLBI, we have produced 8 and 2 GHz VLBI images, at ten epochs spanning the years 1988 to 1996, of the quasar 1156+295. The VLBI data have been taken from the Washington VLBI correlator's geodetic database. We have detected four components and have measured their apparent speeds to be 8.8 $\pm$ 2.3, 5.3 $\pm$ 1.1, 5.5 $\pm$ 0.9, and 3.5 $\pm$ 1.2 $h^{-1}c$ from the outermost component inwards. ($H_0 = 100h$ km s^{-1} Mpc^{-1}, q_0=0.5 throughout paper). These velocities contradict a previously published very high superluminal velocity of 26 $h^{-1}c$ for this source.

Subject headings: Galaxies: Jets - Galaxies: Quasars: Individual (1156+295) - Radio Continuum: Galaxies

1. Introduction

The source 1156+295 is a high polarization quasar (Wills et al. 1992), and an optically violent variable quasar with a redshift of z=0.73 (Hewitt & Burbidge 1989). Tornikoski et al. (1994) discuss the monitoring of this source at optical wavelengths at the Rosemary Hill Observatory, and at the higher radio frequencies by the Metsähovi group. It has also been monitored at lower radio frequencies by the Michigan group (Aller et al. 1985). This quasar is an emitter of high energy γ-rays; EGRET detections of this source are reported by Thompson et al. (1995).

Previous VLBI observations of this source are presented by McHardy et al. (1993, 1990), who measured an apparent velocity of 26 $h^{-1}c$ based on four images at three different frequencies from 1986 to 1988. This velocity made 1156+295 by far the fastest known superluminal source. Vermeulen & Cohen (1994) remark that at the velocity reported by McHardy et al. (1993, 1990) 1156+295 does not even appear to be the tail end of a continuous distribution; its speed is 2.5 times higher than that of the next fastest object in its redshift bin on their μ-z diagram. Since the apparent velocity can be used to set a lower limit on the Lorentz factor, $\Gamma \geq (\beta_{app}^2 + 1)^{1/2}$, this apparent velocity also implies a very high Lorentz factor for the superluminal component of $\Gamma \geq 26$.

2. VLBI Observations

The VLBI results presented here were obtained as part of a project to study EGRET γ-ray blazars using archived geodetic Mark III VLBI observations processed at the Washington VLBI Correlator Facility located at the U.S. Naval Observatory (USNO). Details of the geodetic VLBI observations and the data reduction and model fitting procedures are discussed by Piner & Kingham (1997). We have imaged 1156+295 at 8 and

2 GHz at ten different epochs: 1988 November 25, 1989 April 11, 1989 September 26, 1989 December 18, 1990 June 29, 1992 June 30, 1993 May 7, 1993 July 14, 1996 January 9, and 1996 March 30. Up to three geodetic VLBI experiments were combined to produce single images, with a total of sixteen experiments being used to produce images at ten epochs. When experiments were combined the maximum time separation between experiments was limited to be less than 45 days, so that the time span covered by the combined experiments would be less than the time scale for intrinsic source structure changes. A total of 25 different antennas worldwide were used among all of the imaged observations, with a maximum of six being used for a single experiment.

3. Motion in 1156+295

Figure 1 shows representative 8 and 2 GHz images from the beginning, middle, and end of the time span covered by the observations. The other fourteen images are not presented due to space considerations. Note the differences in scale and resolution between the 8 and 2 GHz images. The outer components are more easily seen in the 2 GHz images and are not as easily seen in the 8 GHz images due to these image's high resolution and the dearth of short baselines in these observations. The spectrum of the components also steepens as the components move out, so that as time goes on they become less easily detected in the 8 GHz images. The earliest 2 GHz image, from 1988 November 25, is from about the same time as the latest image presented by McHardy et al. (1990), and agrees well with their Figure 6*a*. Two components, labeled C1 and C2, are visible in Figure 1*a* in addition to the bright core component. The outermost component, C1, is only detected in those 2 GHz observations with the best dynamic range and (u, v) plane coverage, and is, for example, not seen in the 1992 June 30 2 GHz image. Component C2 is the brightest component at 2 GHz and is seen in all ten 2 GHz images and two 8 GHz images. This component corresponds

to the component that McHardy et al. (1990) measured at 5 GHz on 1988 November 12. The next innermost component, C3, is initially visible only in the 8 GHz images, but later becomes detectable in the 2 GHz images as it moves outward. The innermost component, C4, is detectable only in the later 8 GHz images.

Figure 2 shows the motions of the components over time. Component positions measured at 2 GHz are plotted as squares and their motions are fitted with solid lines, while component positions measured at 8 GHz are plotted as diamonds and their motions are fitted with dotted lines. The component positions were obtained by fitting Gaussian model components to the observed visibilities, and the errors in the component positions are taken to be one quarter of the maximum projection of the beam FWHM along the direction from the core to the component's center. In addition to observations at the ten epochs mentioned above, we have also plotted component positions at 1994 July 8 given by Fey, Clegg, & Fomalont (1996) from a VLBA observation at 8 and 2 GHz. We find that measurements of component positions at 8 GHz are on average displaced outwards from the same component position measured at 2 GHz by 0.65 milliarcseconds (mas). This frequency-dependent separation has been seen by other authors (e.g. Biretta, Moore, & Cohen 1986), and is possibly due to gradients in magnetic field and electron density, such that the $\tau = 1$ surface moves progressively inward at higher frequencies. If we assume that the components move with constant velocity, then performing a least-squares fit of component positions to a straight line gives the apparent velocities of separation. The velocities obtained are 8.8 ± 2.3, 5.3 ± 1.1, 5.5 ± 0.9, and $3.5 \pm 1.2\ h^{-1}c$ for C1 to C4 respectively, where the average of the 8 and 2 GHz velocities has been used for C2 and C3. The one sigma ranges for the ejection times of the two most recent components are 1984 July to 1986 July for C3, and 1989 June to 1992 January for C4. The velocities and standard errors are consistent with each of the components moving with similar velocity; $\sim 5.2h^{-1}c$. This lowers the required Lorentz factor for the superluminal components from $\Gamma \geq 26$ to $\Gamma \geq 5$.

The inner components are not moving significantly faster than the outer components, which leads us to believe that the discrepancy between the velocities measured by us and that measured by McHardy et al. (1993, 1990) is probably not due to a sudden deceleration of the component. We speculate that the anomalously high velocity measured by McHardy et al. (1993, 1990) may be due to a combination of several factors. Their earliest observed point is at their highest observing frequency, 22 GHz, and the position they measure is consistent with the position we estimate for C3 at that time, taking frequency-dependent separation into account. Since their latest point at 5 GHz is consistent with our measured position for the component C2, we speculate that they may have identified these two different components as the same component. This is a danger when connecting components from images made at different frequencies. Their central two points fall between the positions we estimate for C3 and C2 at those times. This may be partly due to an underestimation of the true error bars on the separation, and partly due to a shift of the apparent core position northwards due to a merger of C3 and the core at the frequencies of these observations, 5 and 11 GHz.

We conclude that 1156+295 does not show the extremely rapid superluminal expansion previously measured for this source, and instead has an apparent superluminal velocity much closer to the average for core dominated quasars. This reduces the highest observed speed for superluminal sources from 26 $h^{-1}c$ to 21 $h^{-1}c$ for component K2 of 1308+326 (Gabuzda et al. 1993).

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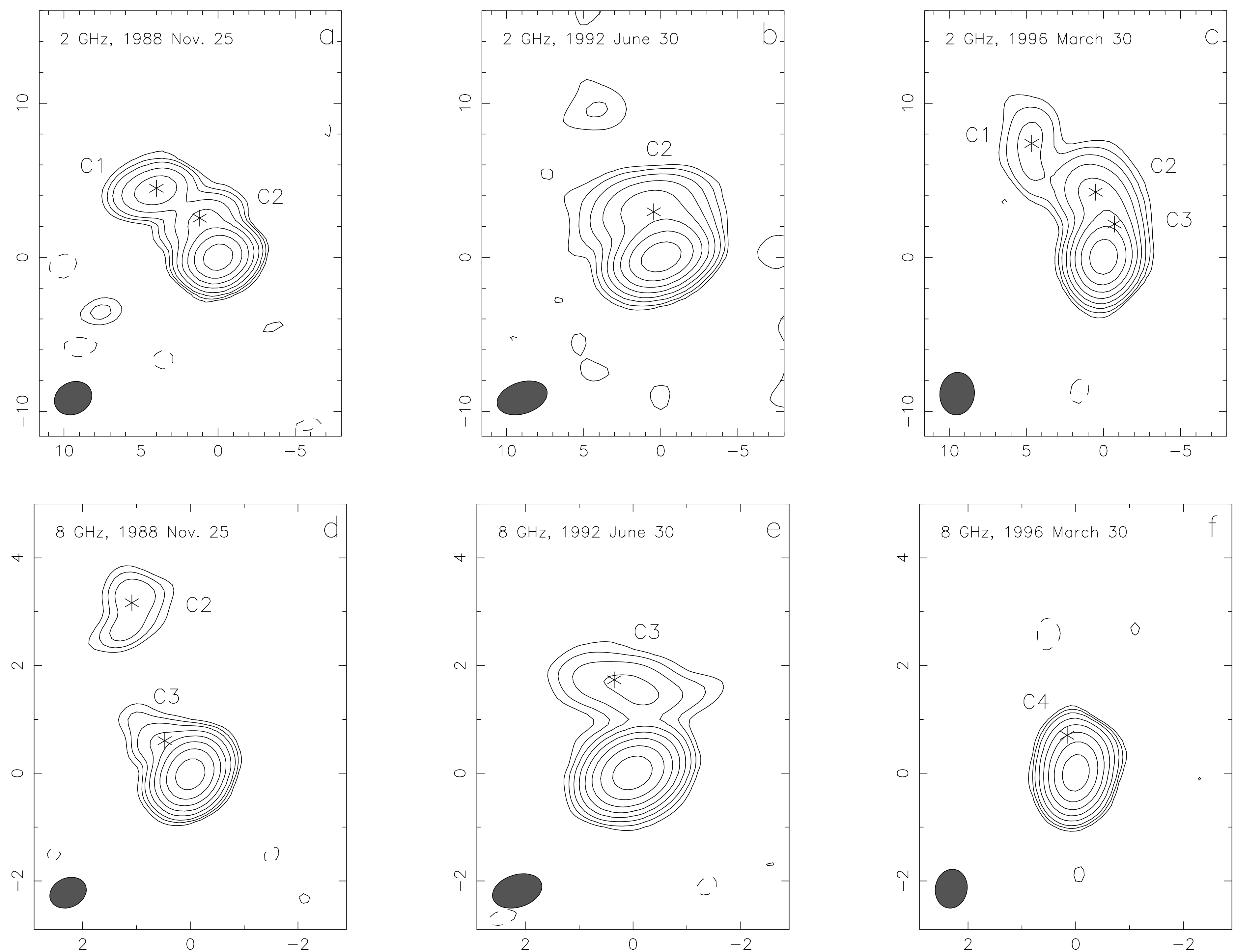
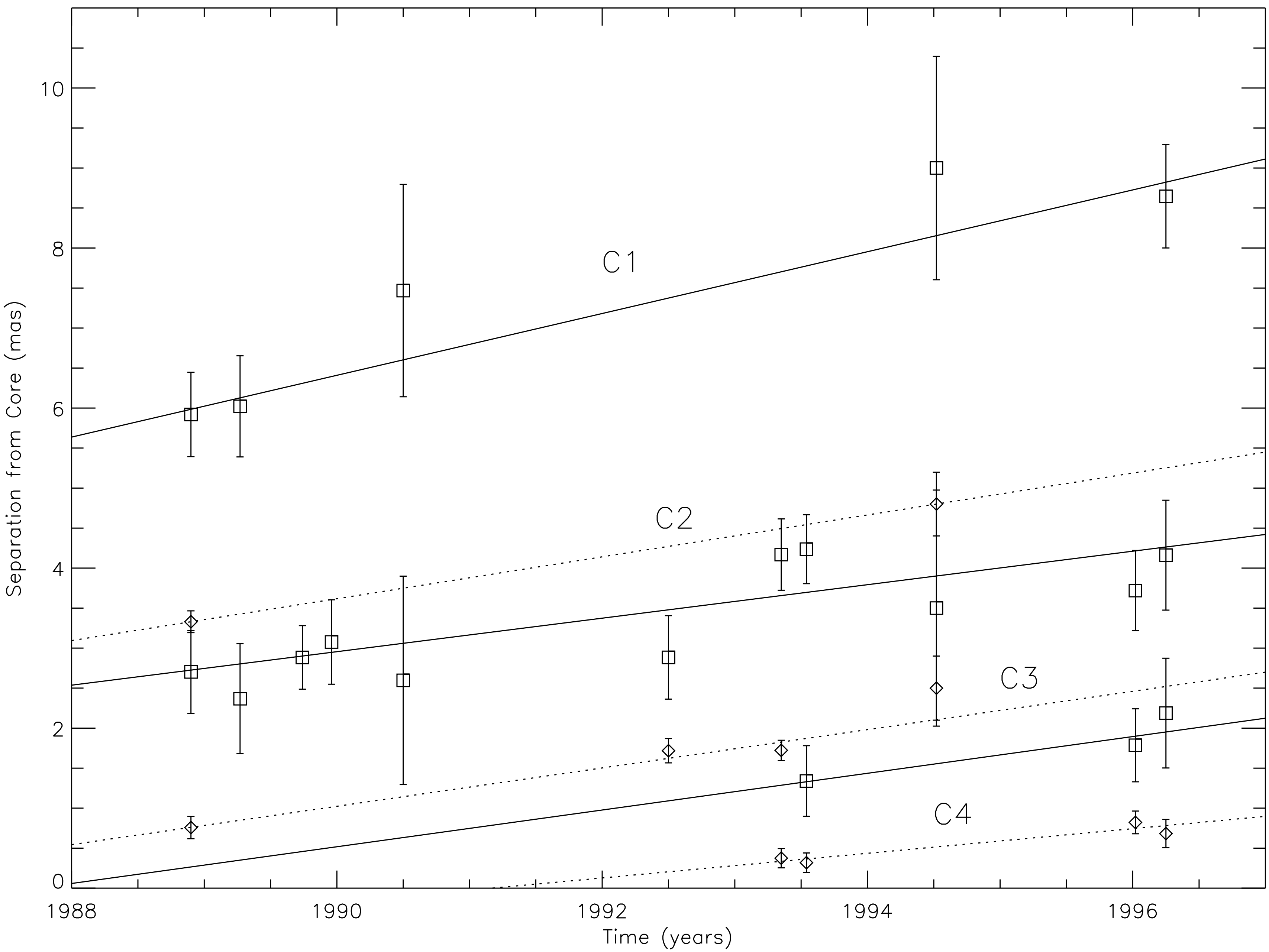
Figure Captions

Fig. 1.— (a)-(c): 2 GHz VLBI images of 1156+295. (d)-(f): 8 GHz VLBI images of 1156+295. Relative right ascension and declination are plotted with tickmark spacings of 1 mas. Contour levels are 2%, 4%, 8%, 16%, 32%, and 64% of the peak brightness. Additional contour levels are −0.7%, 0.7%, and 1.2% for (a), (d), and (f); −0.55%, 0.55%, and 1% for (b); and −0.5%, 0.5%, and 1% for (c) and (e). The FWHMs in mas and position angles of the restoring beams are 2.52 x 2.07 at −63°, 3.36 x 2.05 at −72°, 2.77 x 2.25 at −6°, 0.70 x 0.54 at −66°, 0.94 x 0.60 at −73°, and 0.73 x 0.59 at −10° for (a)-(f) respectively. The peak brightness levels are 1.67, 1.37, 1.15, 1.27, 1.34, and 1.13 Jy beam^{-1} respectively. At least one negative contour is shown in each image. The centers of the fitted component positions are marked with asterisks.

Fig. 2.— Motion of components in 1156+295. The vertical axis shows the separation in mas of the center of the component from the presumed core. Component positions measured at 2 GHz are plotted as squares and positions measured at 8 GHz are plotted as diamonds. The solid lines represent the best fit of the 2 GHz positions to motion with constant velocity, and the dotted lines represent the same fits for the 8 GHz positions.


2 GHz, 1988 Nov. 25
a
C1
C2
2 GHz, 1992 June 30
b
C2
2 GHz, 1996 March 30
C
C1
C2
C3
8 GHz, 1988 Nov. 25
d
C2
C3
8 GHz, 1992 June 30
e
C3
8 GHz, 1996 March 30
f
C4



Separation from Core (mas)
0
2
4
6
8
10
1988
1990
1992
1994
1996
Time (years)
C1
C2
C3
C4